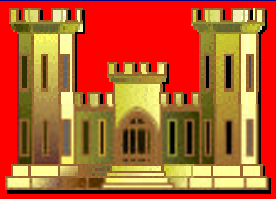
Infrastructure Engineering and Management Research Thrust Area

Earthquake Engineering Program

D. E. Yule

US Army Corps of Engineers

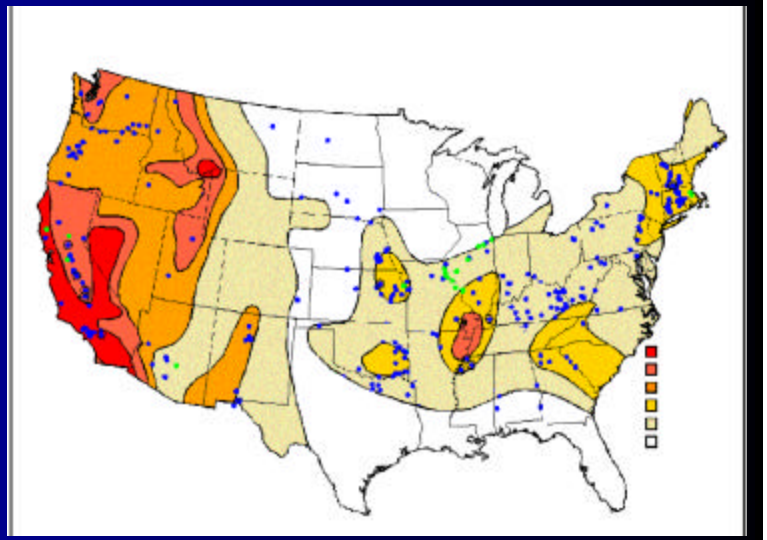
Engineering Research and Development Center



Earthquake Engineering Research Program

Problem

- Corps has 200 dams and 73 intake towers in areas with significant seismic hazards
- Most dams were constructed when earthquake engineering was in its infancy
- Using current technology, most of these would be judged seismically inadequate
- Replacement costs of these structures could reach $20 billion



Seismic zone map showing SMIP project sites

Purpose

- To improve our ability to predict the performance of a dam under seismic loads, and to improve our ability to design and construct cost-effective remediation

Major Thrusts

- Engineering geology / seismology
- Geotechnical earthquake engineering
- Structural earthquake engineering

Mormon Island Dam, CA remediation

Target Structures

- Embankment dams
- Concrete dams
- Intake tower / outlet works

Sardis Dam, MS remediation

Importance

- EQEN is ***only*** federal funded program focused on seismic safety of dams

- Coordination & Leveraging
  - National Earthquake Hazard Reduction Program (FEMA,USGS)
  - NSF - MCEER , PEER, MAEC and universities
  - FHWA Highway Seismic Research Program
  - US Bureau of Reclamation, BC Hydro
  - UJNR US-Japan Panel on Wind and Seismic Effects,
  - **Districts (reimbursable work)**

EQEN - Embankment Dams

Ground Motions

Geology / Seismology

Engrg Ground Motion Analysis System

Site Characterization

Vs Database
Geophysical Methods
Penetration Testing

Performance Assessment

Newmark Analyses Behavior of Liquefying Soils
Failure Mechanisms & Damage Assessment
Liquefaction at Depth

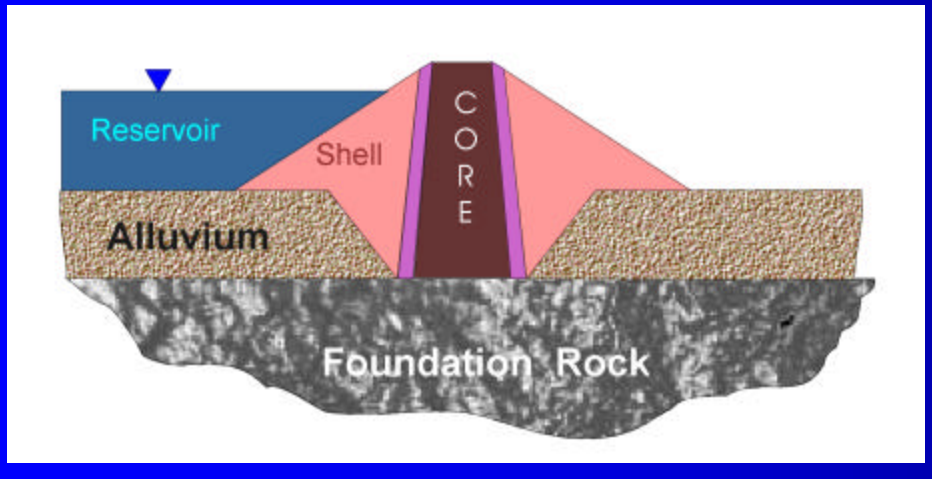
Primary Analysis Tool

Large Deformation Analysis of Embankment Dams

Assessment & Remediation

EQEN Phase II

Seismic Evaluation and Rehabilitation Program



Products

EQEN - Concrete Dams and Outlet Works

Ground Motions

Intake Towers

Outlet Works

Quantify Ductility

Subbottom Absorption

Conventional Concrete Dams

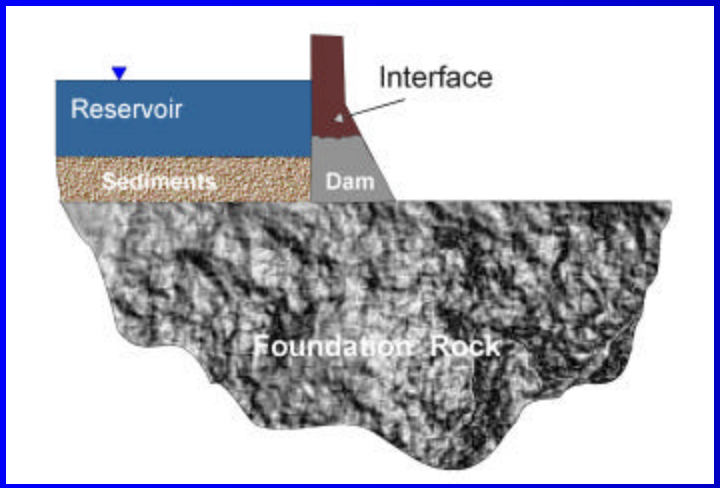
Retaining Walls

Primary Analysis Tool

Time - History
Non - Linear Analysis

Moment / Shear / Thrust

Post - Processors



Products

Earthquake Engineering Research Program

Accomplishments and Breakthroughs

Seismic dam safety becomes a priority

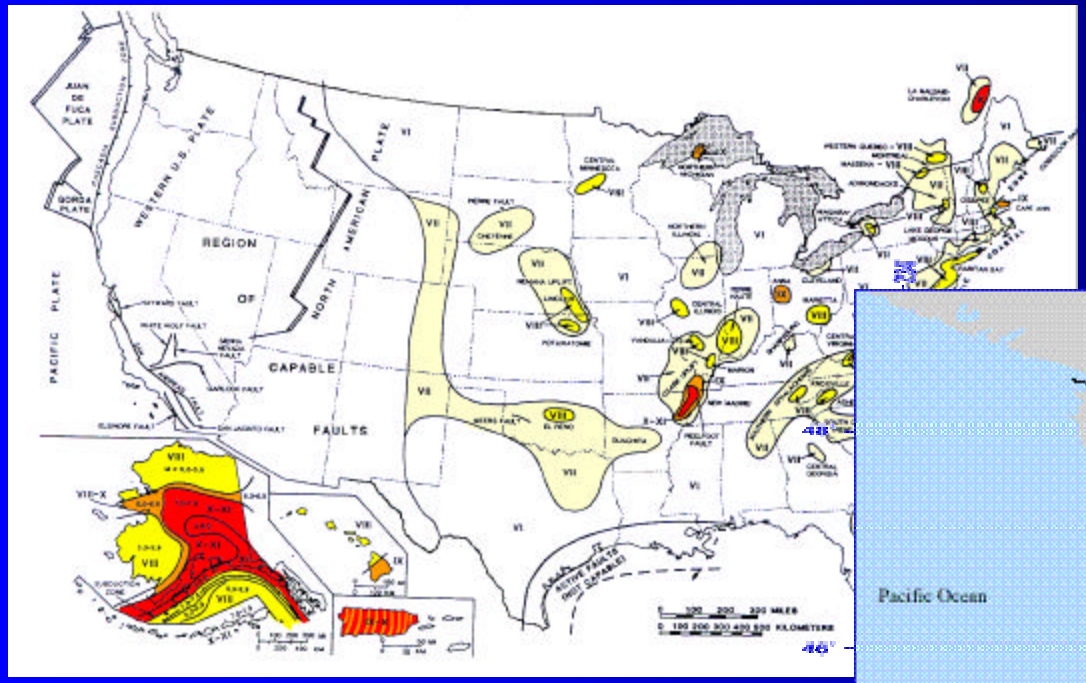
Near failure of Lower San Fernando Dam
San Fernando Earthquake - 1971

Mormon Island Dam, CA remediation

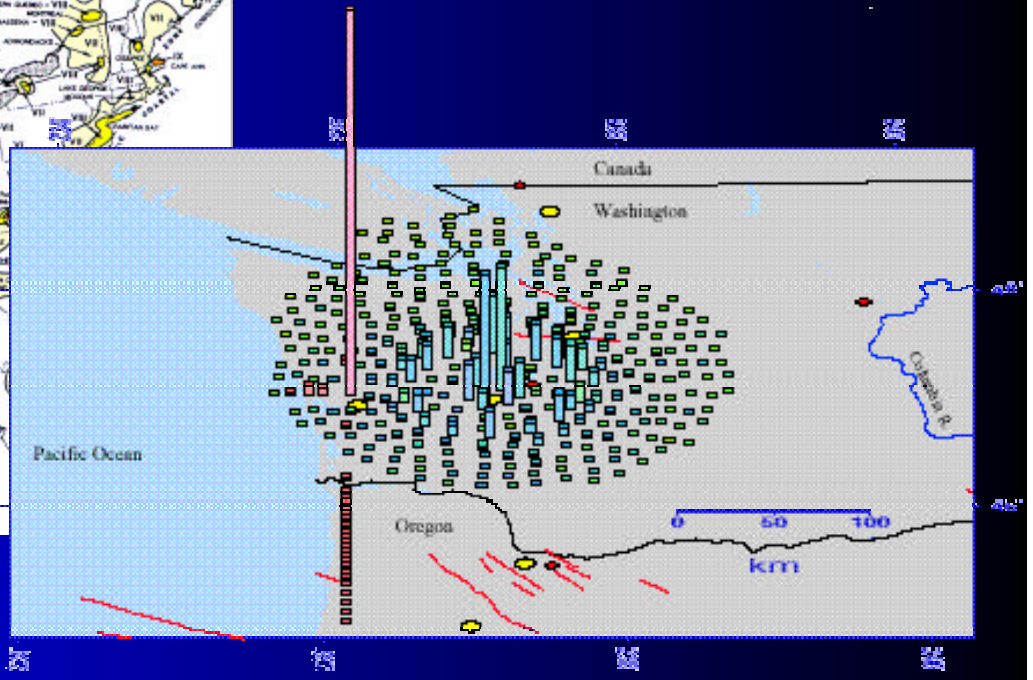
Sardis Dam, MS remediation

Earthquake Engineering Research Program

- **Geological - Seismological Evaluations**
  Incorporated latest knowledge into methods for geological-seismological evaluations of earthquake hazards enabling accurate site-specific ground motions for potential earthquakes affecting Corps projects



Seismic source zones for U.S.



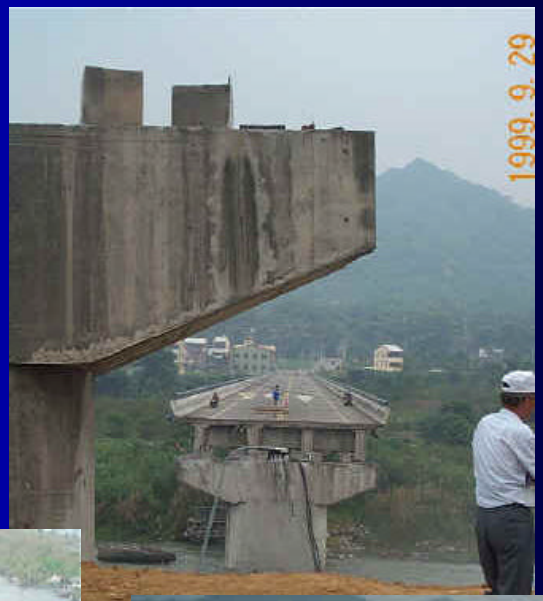
Azimuth Decomposition of Seismic Hazard.

Continuing transition of geologic & seismologic research into engineering

Earthquake Engineering Research Program

- **Geological – Seismological- Geotechnical Evaluations: Earthquake Reconnaissance**

Taiwan Earthquake Photos

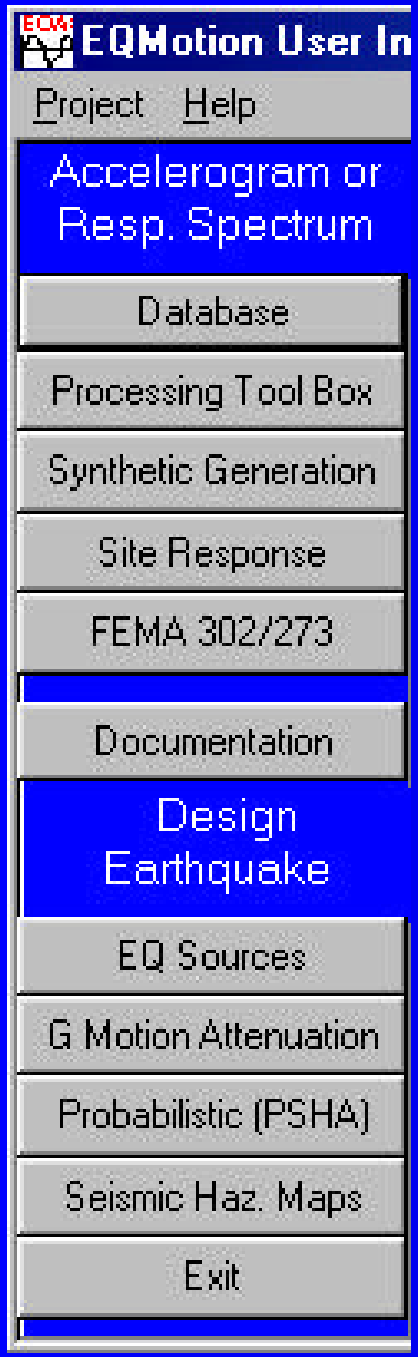


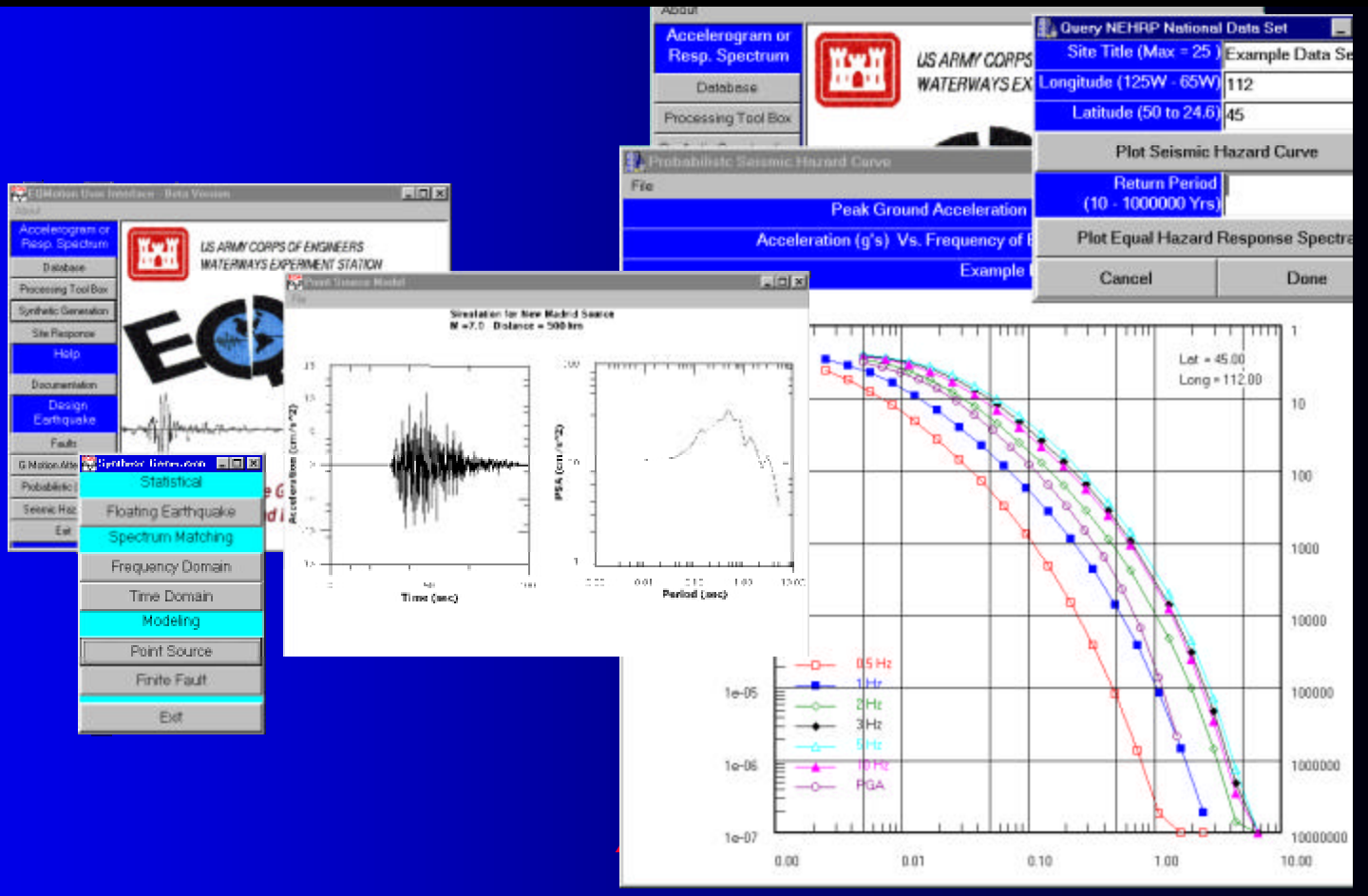
Continuing transition of geologic & seismologic research into engineering

Engineering Ground Motion Analysis System

Windows based tool box for site seismic hazard assessment and selection of policy compliant ground motions for engineering analysis of hydraulic structures

Development of site-specific ground motions and spectra for dynamic analyses



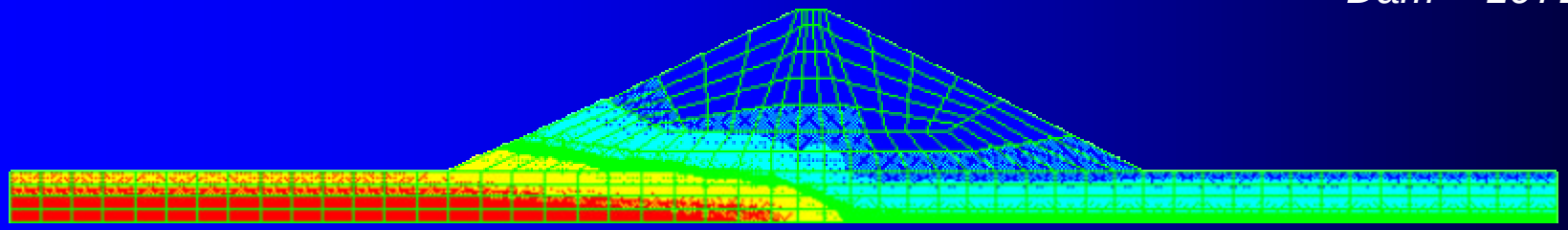


Earthquake Engineering Research Program Embankment Dams

Research Thrust Areas

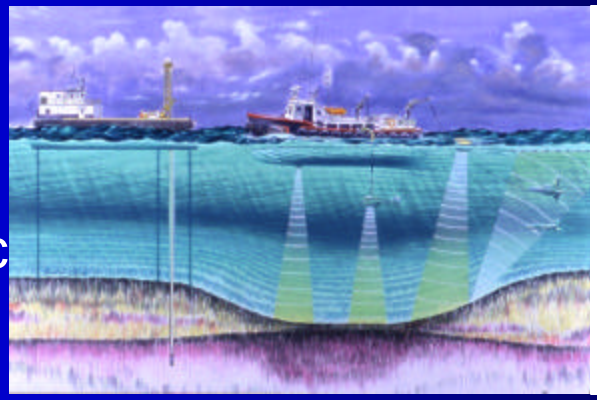
- **Site Characterization**
- **Liquefaction**
- **Large Deformation Analysis**

Slide in Lower San Fernando Dam - 1971

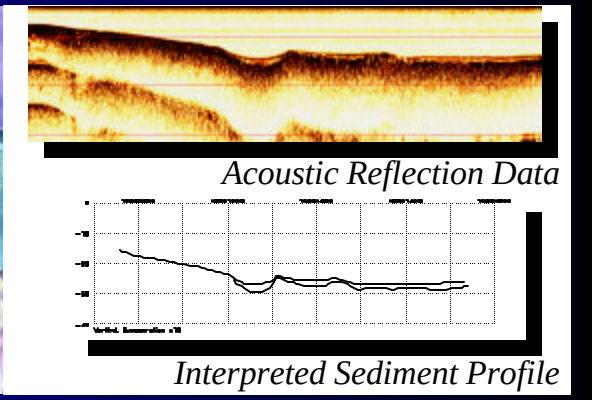


Earthquake Engineering Research Program

- **Geophysical Methods for Site Characterization**
  Waterborne Geophysics
  - Subbottom material identification, distribution, and volume
  - Side scan image mosaic



Subbottom Profiling System



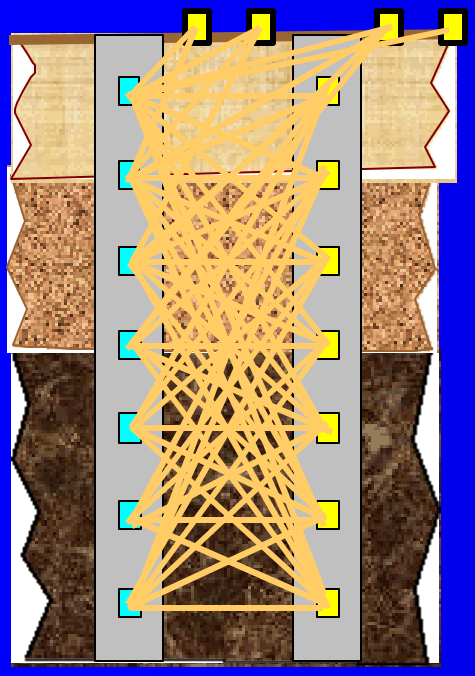
Arkabutla data

Advanced Characterization
Detailed Imaging

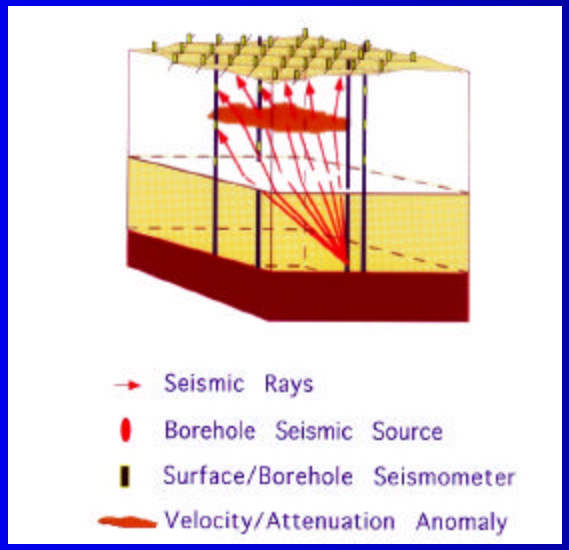
Side scan sonar of Arkabutla control structure

Earthquake Engineering Research Program

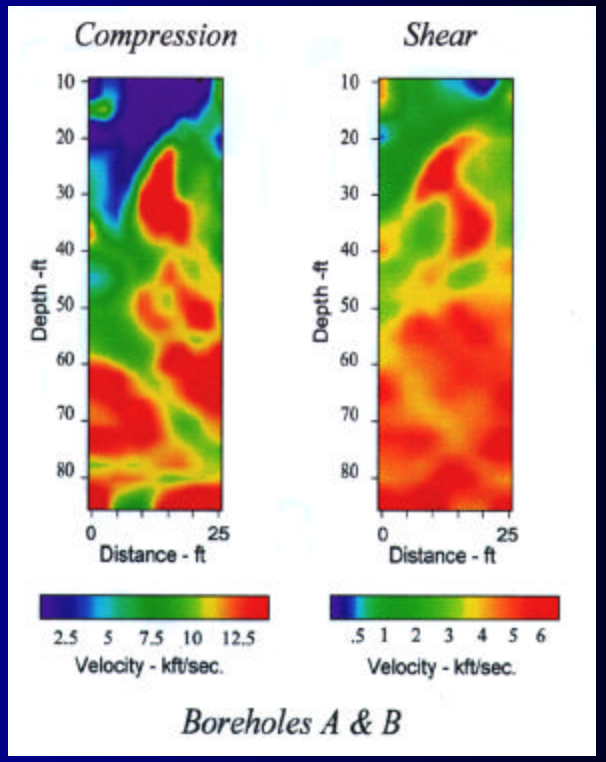
- **Geophysical Methods for Site Characterization Land based methods**
  - **Advanced Data Content - Improved Analysis**
  - **Increased Coverage - Less Cost**



2-D

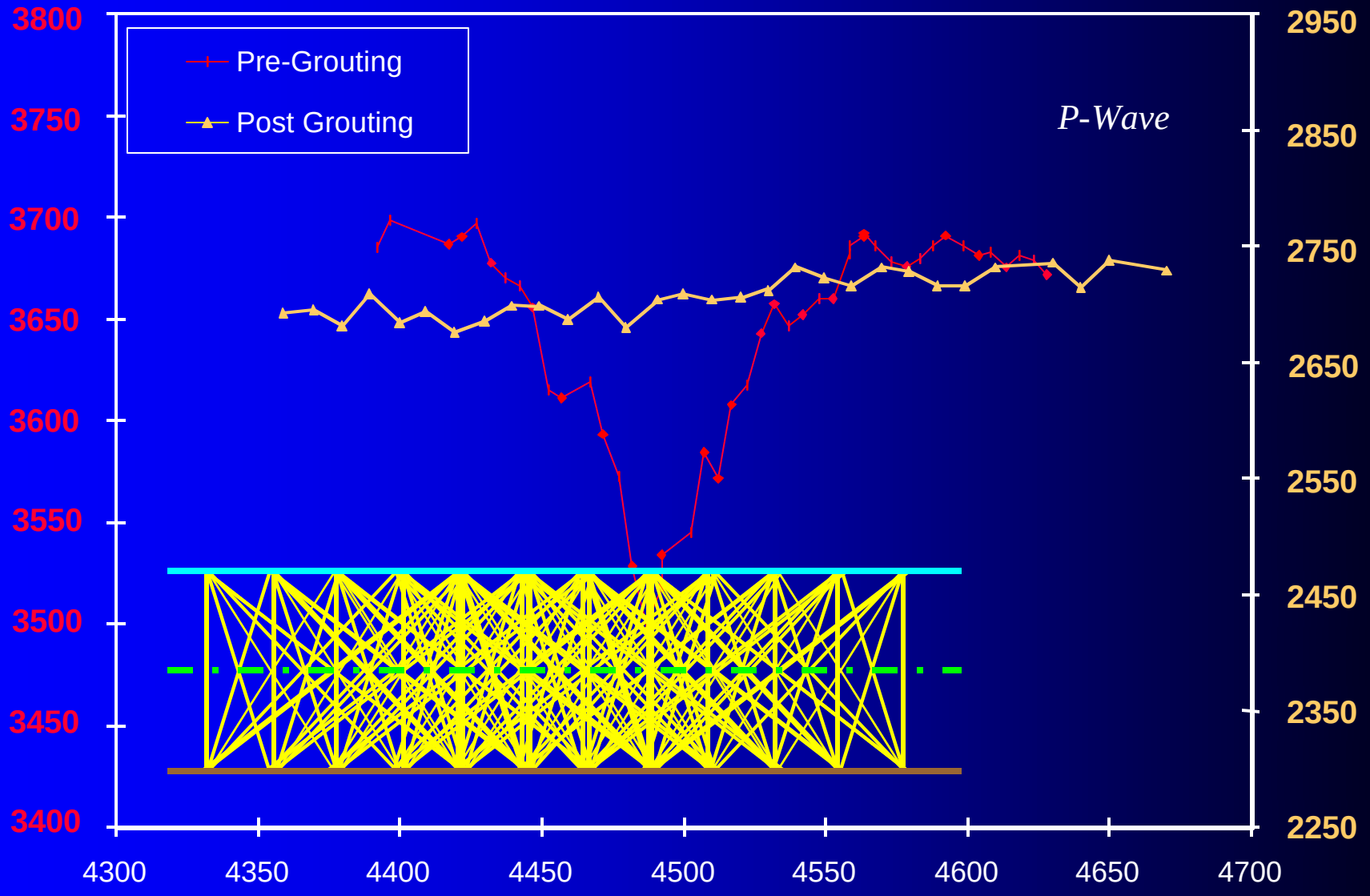


3-D



Success Dam, CA
borehole tomography

Through-the-Dam Tomography

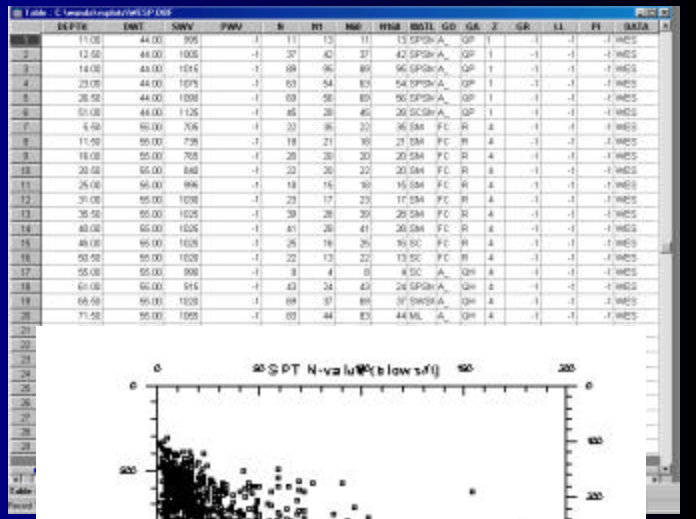


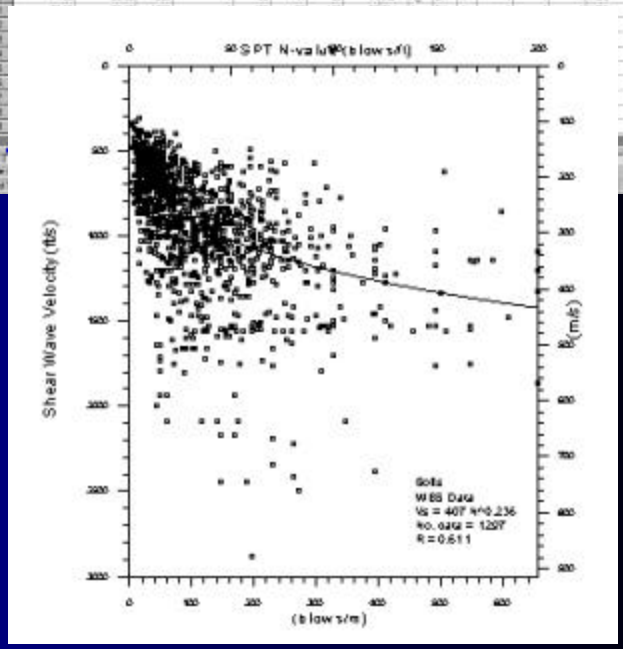
Earthquake Engineering Research Program

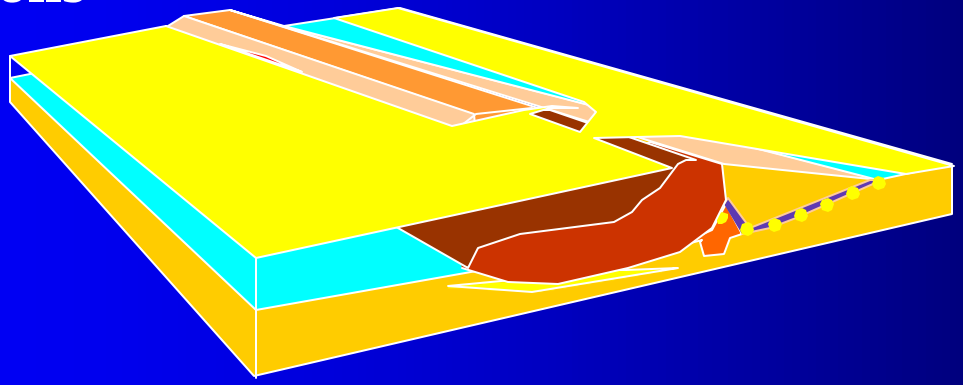
- **Shear Wave Velocity Database -** developed to support screening analysis

- **Newmark Sliding Block Analysis –**
  validated by compilation and investigation of case histories

- **Criteria for identifying liquefiable fine-grained soils**

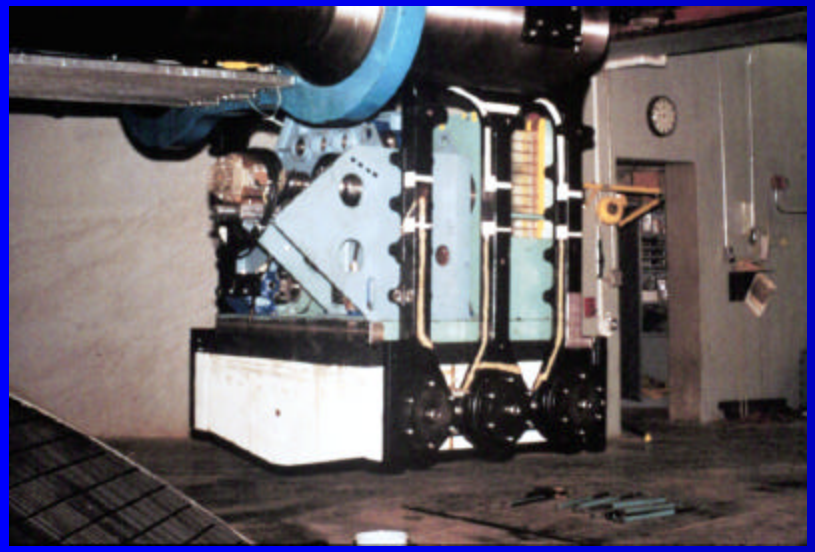




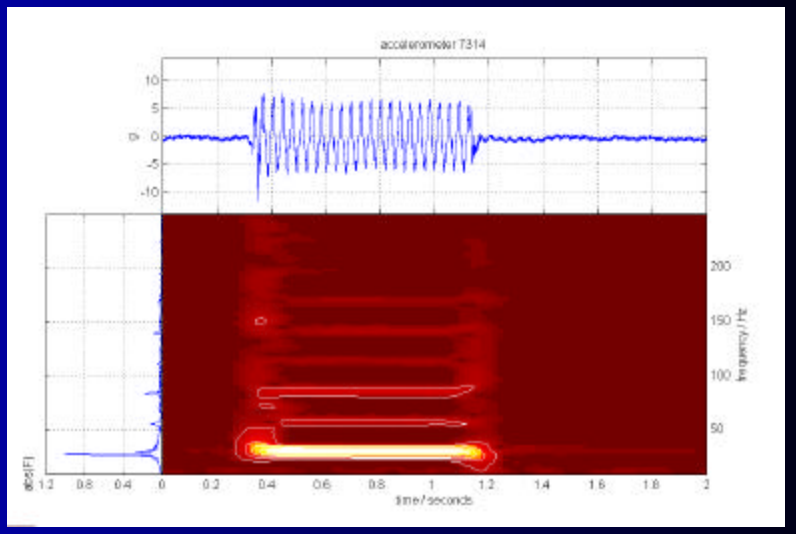


Earthquake Engineering Research Program

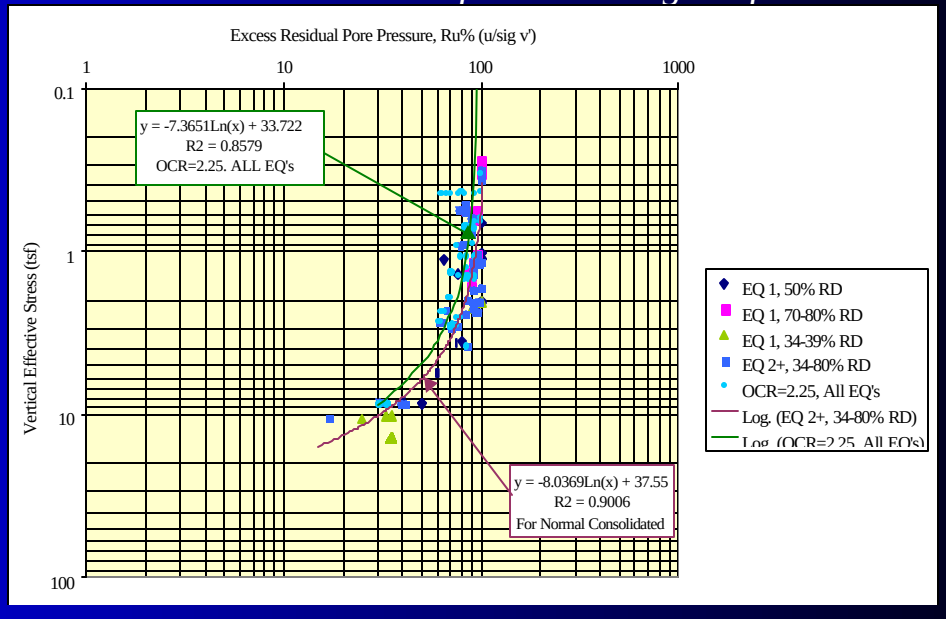
- **Research into the behavior of liquefying soils**



Earthquake shaker mounted on centrifuge arm



Wavelet analysis of soil response to earthquake loading response

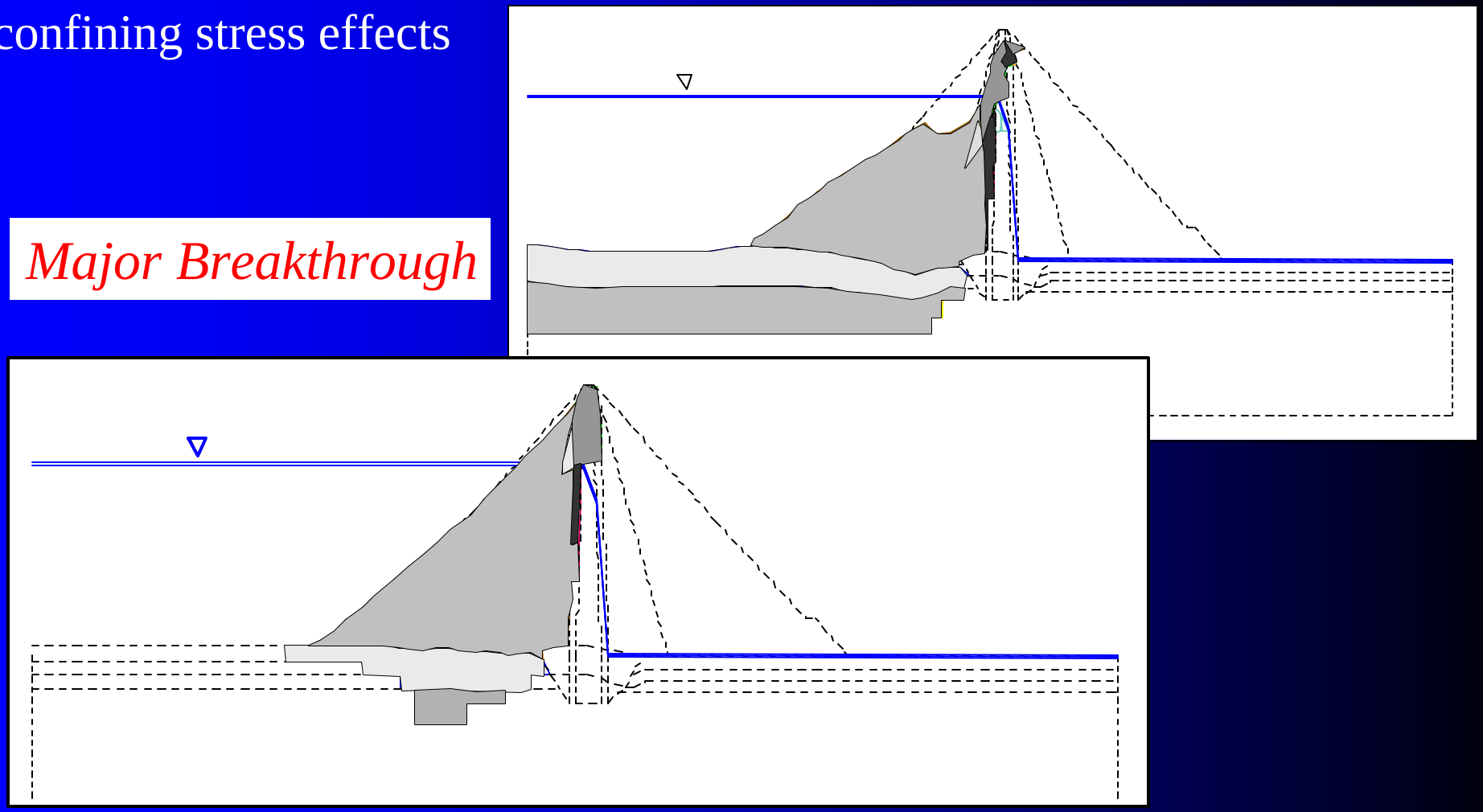


Dynamic Induced Residual Excess Pore Pressure Limit

Earthquake Engineering Research Program

- **Liquefaction:** Improve state-of-the-practice for determining confining stress effects

Major Breakthrough



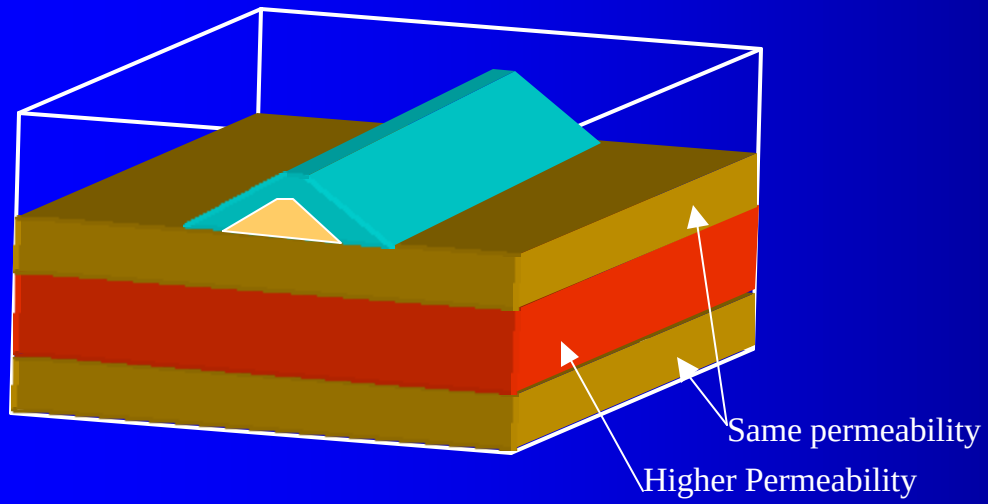
Effect of current findings on limiting depth of liquefaction, Success Dam, CA

Earthquake Engineering Research Program

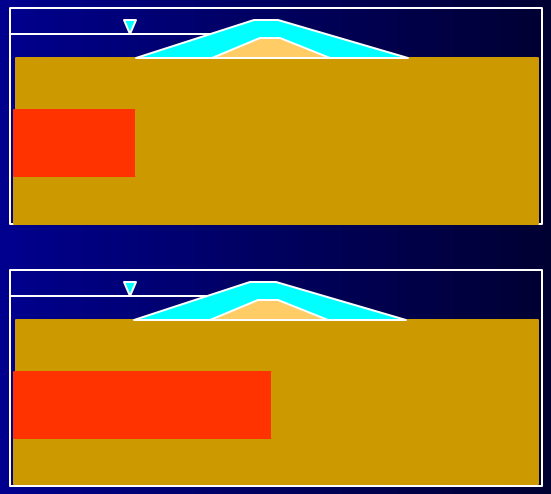
- **Failure Mechanisms and Damage:** Improve state-of-the-practice for determining performance of dams in response to liquefaction of soils

Slide in Lower San Fernando Dam - 1971

Centrifuge (physical) modeling



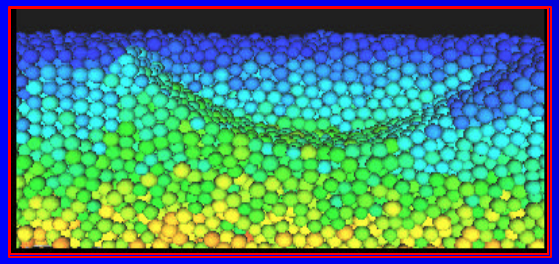
Effect of layer permeability



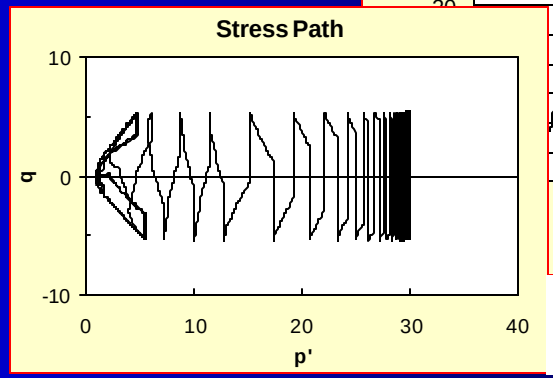
Extent of liquefiable layer

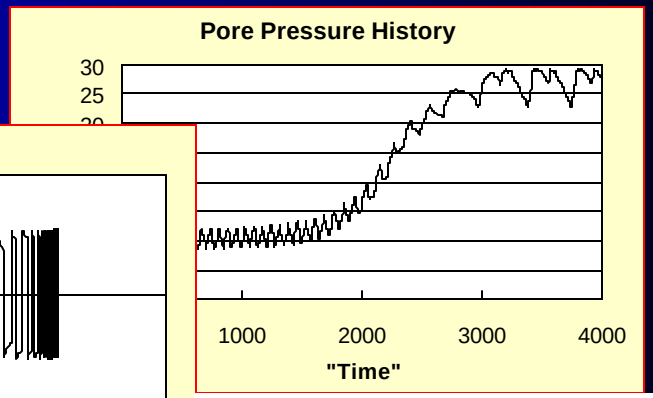
Earthquake Engineering Research Program

- **Seismic Stability and Deformations of Earth Structures and Foundations:** numerical modeling to improve the estimation of post-earthquake deformation.

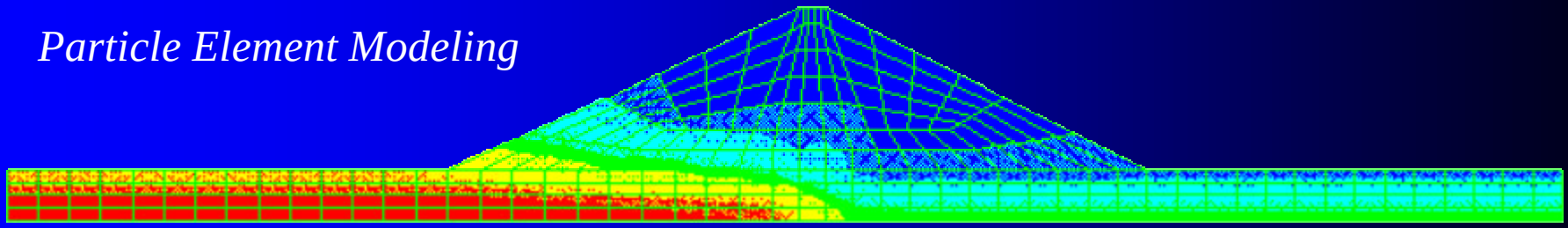


Particle Element Modeling





Coupled with Stress



Idealized dam initial pore water pressure

Infrastructure Engineering and Management Research Thrust Area

Earthquake Engineering Program

D. E. Yule

End of Presentation

Questions

US Army Corps of Engineers

Engineering Research and Development Center